THE EFFECT OF
GEOMAGNETIC MICROPULSATIONS
ON MAD SYSTEMS

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NAVAL OCEANOGRAPHIC OFFICE

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TECHNICAL REPORT

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FOREWORD

One type of background noise that can interfere with proper magnetic anomaly detector (MAD) target identification is caused by magnetic storms and micropulsations. This report details knowledge gained about this type of noise during a Naval Oceanographic Office study. The purpose of this report is to pass this information on to those directly involved in MAD operations.

J. E. AYRES
Captain, USN
Commander

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Naval Oceanographic Office established a special geomagnetic recording site in order to study the effects of geomagnetic storms and micropulsations on magnetic anomaly detectors used by naval aircraft engaged in antisubmarine warfare operations. This report presents the results of this study.
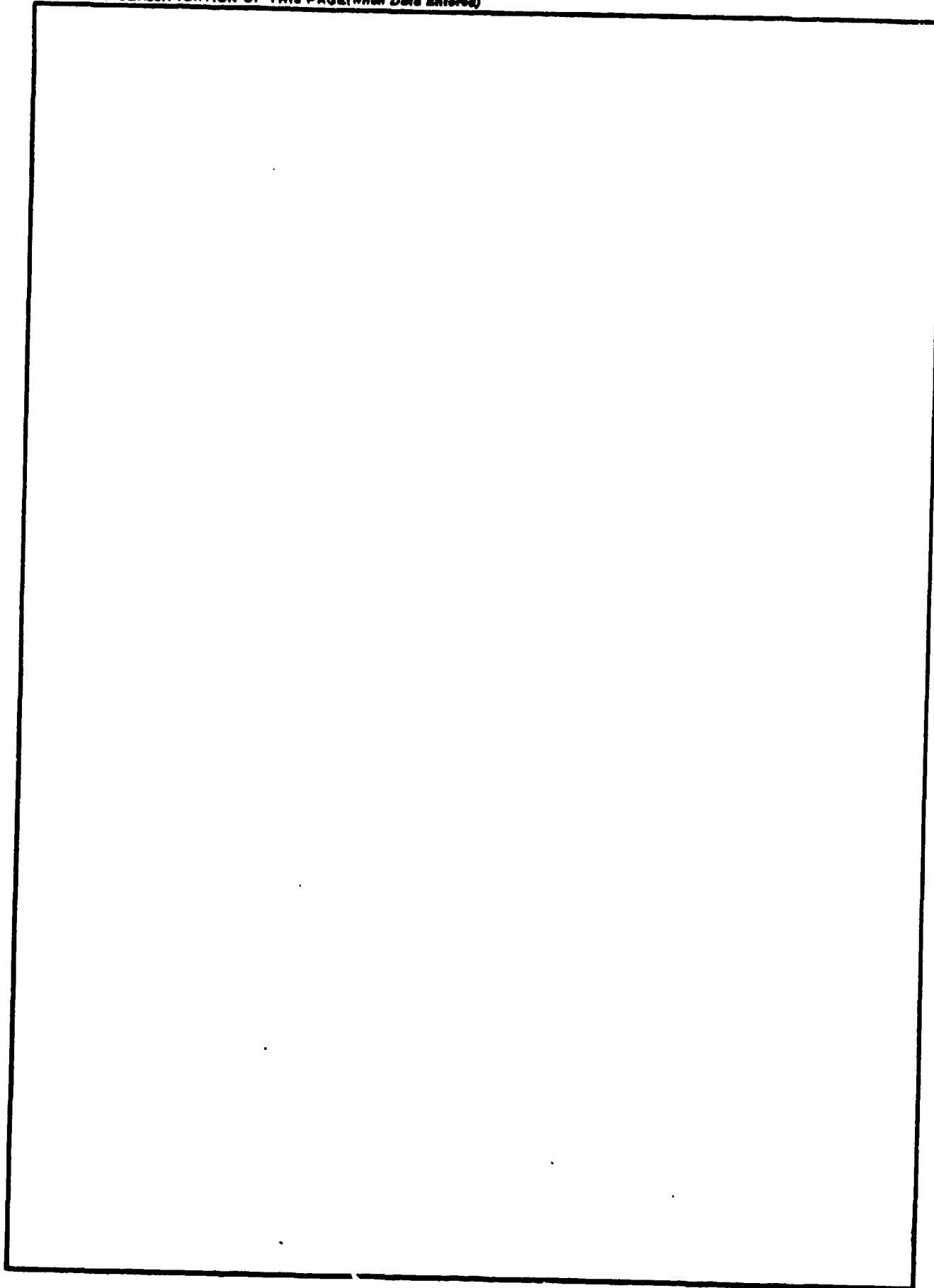
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INTRODUCTION

The Survey Technology Branch of the Naval Oceanographic Office (NAVOCEANO) has completed a study of the effects of magnetic storms and micropulsations on magnetic anomaly detectors (MAD) carried aboard U.S. Navy aircraft used in antisubmarine warfare. This report contains the results of this study.

BACKGROUND

Many reports and papers have been written about magnetic storms and micropulsations. Much of this literature is concerned with defining causative mechanisms or with correlating these micropulsations to other phenomena such as sunspot activity. However, relatively little has been reported on the way in which magnetic field disturbances affect the operation of MAD detectors. The importance of investigating the effects of magnetic disturbances on MAD detectors has been defined in reports issued by the U.S. Naval Air Development Center and the Pacific Naval Laboratory (Miles and Lepping, 1962; Jacobs and Wright, 1966).

Two different types of magnetometers are used by fleet ASW aircraft, the ASQ-10A and the ASQ-81. Both instruments respond to changes in total magnetic intensity, and both are equipped with bandpass filters. These filters are designed so that the frequencies that comprise the rather small anomaly created by a submarine can be separated from frequencies natural to the Earth's main magnetic field.

The ASQ-10A, the older of the two magnetometer systems in current fleet use, was used in this study. Figure 1 shows the amplitude response curve for the ASQ-10A filter. This filter is designed to reject frequencies below 0.02 Hz and above 3.0 Hz, and is centered around the most common frequencies found in submarine signals.

Normal daily variations in the magnetic field are very long period, low-frequency changes which are excluded by the filter. Much of the activity that occurs during a magnetic disturbance is also low frequency and is excluded by the filter. However, superimposed on these low-frequency changes are higher frequency pulsations which pass through the filter and appear as noise on the MAD trace. This type of noise seldom simulates a submarine signal, but it can interfere with proper signal identification.

The general term used to define short-period, high-frequency magnetic activity is "geomagnetic micropulsations." The word "micropulsations" tends to be somewhat misleading, because the pulsations encompass periods of tenths of a second to several minutes and vary in amplitude from one hundredth of a gamma to 10 gammas. Table 1 defines the general classification of geomagnetic micropulsations. The various categories of pulsations shown in the table have been established, because observers have often noted that certain amplitude and frequency relationships are repeated. As magnetometers have improved and become more sensitive they have allowed definition of the lower amplitude, higher frequency categories of pulsation activities.

TABLE 1.   CLASSIFICATION OF GEOMAGNETIC
MICROPULSATIONS

TYPE PULSATION	PERIOD (seconds)	AVERAGE AMPLITUDE (gammas)
Pc1	0.2-5	0.05-0.1
Pc2	5-10	0.1-1
Pc3	10-45	" "
Pc4	45-150	" "
Pc5	150-600	1-10
Pi1	1-40	0.01-0.1
Pi2	40-150	1-5

(After Jacobs, 1970)

Geomagnetic pulsation activity is not confined to periods of magnetic storms; pulsation activity can also occur when the field is considered to be relatively quiet. However, pulsation activity is definitely greatest during periods of magnetic field disturbances.

The designation Pc in table 1 refers to pulsation activity that is considered to be "continuous." Pc activity has a rather constant frequency and amplitude and generally lasts from several minutes to several hours at a time. The Pi designation refers to irregular pulsations that have mixed frequencies and amplitudes and often occur in sporadic bursts of activity.

By combining the information in table 1 with frequency and amplitude characteristics of the ASQ-10A filter (fig. 1), the noise levels of filtered pulsations can be estimated. Probable noise levels are contained in table 2. The instrument noise level, or sensitivity, of an ASQ-10A magnetometer system is about 0.1 gamma. Table 2 shows that this system is particularly susceptible to Pc2- and Pc3-type pulsations.

TABLE 2.   PROBABLE MICROPULSATION AMPLITUDES THROUGH
AN ASQ-10A BANDPASS

TYPE	PERIOD (sec)	FREQUENCY (Hz)	AVERAGE AMPLITUDE OBSERVED (gammas)	PROBABLE ASQ-10A FILTERED AMPLITUDE (gammas)
Pc1	0.2-5	5.0-0.2	0.05-0.1	Below ASQ-10A Noise Level
Pc2	5-10	0.2-0.1	0.1-1	0.1-0.9
Pc3	10-45	0.1-.02	0.1-1	0.0-0.8
Pc4	45-150	.02-.007	0.1-1	Below ASQ-10A Noise Level
Pc5	150-600	-	Below ASQ-10A Bandpass Frequency	
Pi1	1-40	1.0-.025	0.01-0.1	Below ASQ-10A Noise Level
Pi2	40- 50	-	Below ASQ-10A Bandpass Frequency	

2

INSTRUMENTATION

In order to learn more about the effect of micropulsation acitivity
on MAD equipment, a magnetic recording site was established in May 1969
by NAVOCEANO personnel at the U.S. Naval Explosive Ordnance Disposal
Facility at Stump Neck, Maryland. This recording site is about 30 miles
south of Washington, D.C. The area is considered to be magnetically
quiet, with no industrial magnetic noise sources. The principal instru-
ments used for observations were a rubidium vapor magnetometer and an
ASQ-10A magnetometer. The rubidium magnetometer provided unfiltered pulsation
data, while the ASQ-10A provided filtered data. The rubidium vapor
magnetometer data allows an observer to discern fluctuations of 0.05 gamma
and more in the total field vector. As mentioned above the ASQ-10A mag-
netometer system is generally regarded as being capable of a 0.1 gamma
sensitivity, at least when used as a ground station. The allowable in-
flight noise level of the system is 0.2 gamma.

From May 1969 through April 1972, there were 150 periods during which
magnetic data were acquired. These periods varied in length from 2 to
8 hours depending on the activity of the magnetic field. In general,
observation periods were longest on days of higher magnetic field activity.

MAGNETIC ACTIVITY INDICATORS

Several different methods have been developed for indicating the
general level of magnetic activity during any day. Two of the more common
indicators are the "K" and "A" indices.

The "K" index on a scale of 0 to 9 is a measure of the range of
magnetic activity for every 3 hours Greenwich time. Thus, a total of eight
"K" values are defined for each day. The "A" index on a scale of 0 to 400
is an indication of the magnetic field activity for a Greenwich day. The
"A" index is derived by converting the eight "K" values to the "A" scale
and averaging them for a Greenwich day. Each magnetic observatory defines
its "K" index and "A" index for any given day. Eventually, these indices
are combined to define the Kp or Ap, that is, the planetary "K" and "A"
index for the day.

A latitude effect on the severity of magnetic activity has been established.
The intensity of magnetic activity increases from low to high latitudes
reaching a peak in the auroral zones. From the auroral zone there is a slight
decrease in activity toward the magnetic poles. Magnetic activity is also
enhanced in a narrow band along the magnetic equator. More precisely, lati-
tude dependence of magnetic activity is defined in terms of geomagnetic
latitude rather than geographic latitude. Figure 2 shows the relationship
between geomagnetic and geographic latitude. Latitude effect is taken into
consideration when the "K" indices are established for an observatory. For
example, at Sitka, Alaska, a "K" of 3 is equal to a range of 40 to 80 gammas
above the station base line, but a "K" of 3 at Fredericksburg, Virginia, is
equal to a range of 20 to 40 gammas above the station base line. Consequently,
when these "K" values are converted to "A" values, an "A" of 25 at Sitka defines
a much larger range of gammas than an "A" of 25 at Fredericksburg. All indices
in this report are based on observations at Fredericksburg.

3

On the "A" scale the magnetic field is considered to be moderately
disturbed at values of 25 to 50 and severely disturbed at 50 or more.

In this study one of the points of interest was the relationship of
the "A" index to the effect of geomagnetic pulsation activity on MAD sys-
tems. The interest in this relationship stems from the fact that the "A"
index is a very widely distributed piece of information. It is included
in the geoalerts broadcast by WWV and WWVH each hour and in forecasts
prepared by the Fleet Numerical Weather Center. Therefore, if the "A"
index could be applied to operation of the MAD system it would be a
readily available source of information for interpreting unusual MAD
noise patterns.

RECORDED DATA SAMPLES

Figure 3 shows a data sample recorded during a magnetic storm. This
day's "A" index of 30 meant that the field was moderately disturbed.. The
upper trace shows a rubidium vapor magnetometer recording of unfiltered
data. The lower trace is an ASQ-10A recording of filtered data similar
to those recorded aboard ASW aircraft.

The unfiltered upper trace shows a series of continuous micropulsa-
tions with an average period of 15 seconds and an average amplitude of
0.4 gamma. Examination of the ASQ-10A trace shows that the filter in
the MAD system reduced these pulsations from the original 0.40 gamma
average amplitude to about 0.24 gamma. This can be explained by examining
the amplitude response curve presented in figure 1. The pulsations had
an average period of 15 seconds or 0.067 Hz. The response curve indicates
that 64 percent of the amplitude of frequencies around 0.067 Hz will pass
through the filter. In the sample recording 0.24 gamma or 60 percent of
the original pulsation amplitude of 0.40 gamma passed through the filter,
a reasonably good agreement between expected and observed results. Any
difference is undoubtedly due to use of an average frequency when several
frequencies are actually involved.

Figure 3 is a typical display of pulsation activity during periods
of magnetic storm activity. These rather short-period pulsations were
superimposed on longer period field changes. The longer periods, up to
several minutes in length, were excluded by the MAD filter.

At the lower left corner of the ASQ-10A record is an illustration
of a submarine signal shape. The amplitude of the signal obviously depends
on the distance between submarine and the aircraft. The amplitude shown
(0.4 gammas) is typical of target and aircraft separation of several
hundred feet or more. This type of pulsation activity could interfere
with proper signal identification by tending to be mistaken for or
masking a true target signal.

4

Figure 4 shows part of a record observed when the "A" index was 12, a day on which the magnetic field was quiet. The format of this illustration is the same as that of figure 3.

The unfiltered upper trace shows a series of continuous pulsations with an average period of about 30 seconds and an average amplitude of about 0.5 gamma. The ASQ-10A trace shows that these pulsations have been attenuated to an average amplitude of about 0.13 gamma. These long-period pulsations are generally of higher amplitudes than the pulsations shown in figure 3; however, because of their lower frequencies, they were attenuated more by the MAD bandpass.

The type of pulsation shown in figure 4 is common during quiet periods. These pulsations usually occur during the morning hours. Usually, when this type of pulsation occurs during quiet periods, it lasts for several minutes.

This type of pulsation was observed quite often on ASQ-10A recordings at the observatory, where the magnetometer was stationary. It is very possible that this type of pulsation would be indistinguishable from other noise sources on an ASW aircraft equipped with an ASQ-10A. Pulsations of this amplitude would probably be more easily observed with an ASQ-81 magnetometer system, which is more sensitive and has a lower noise level.

Figure 5 shows traces recorded when the "A" index was 56, that is, the field was severely disturbed. The unfiltered upper trace shows short-period pulsations superimposed on a longer period field change. In this case, the short-period pulsations simulate a possible target signal just prior to 1615. This figure illustrates that pulsation activity passing through the ASQ-10A filter occasionally can produce a single target-like signal. In an actual ASW exercise, this false signal could cause a loss of time in rechecking the location at which the signal occurred.

In the 150 periods of data recording, the "A" index was 25 or more on nine occasions. On each of these occasions there was a wide variety of pulsation activity, much of which was of the proper frequency to pass through the ASQ-10A bandpass. When the magnetic field was moderately to severely disturbed, pulsation activity was observed on the ASQ-10A trace from 20 to 80 percent of the time. The usual amplitude of pulsations on an ASQ-10A trace during disturbed periods was between 0.2 and 0.6 gamma.

In additon to periods during which the magnetic field was definitely disturbed, there were 11 generally quiet periods with "A" index less than 25 in which pulsation activity was observed on the ASQ-10A trace. Pulsation activity on the ASQ-10A trace during quiet periods lasted only a few minutes at a time as previously noted.

There were 12 other periods of observation in which intermittent pulsation activity was observed on the unfiltered magnetometer trace. However, during these periods the pulsations did not pass through the filter and appear on the ASQ-10A trace.

5

The following is a summary of the observed pulsation data:

TOTAL PERIODS OF OBSERVATION	150	
	Number of obs.	% of total obs.
Major activity, pulsations observed on ASQ-10A trace 20 to 80 percent of the time, A ≨ 25	9	6
Minor activity, pulsations observed on ASQ-10A trace up to 20 percent of the time, A < 25	11	7
Activity with no effect on ASQ-10A trace, A < 25	12	8
Total periods with pulsation activity	32	21

The geomagnetic latitude of the NAVOCEANO recording site is 52°N. Pulsation activity at this location is probably typical of pulsation occurring over much of the ASW operating areas of the North Atlantic and North Pacific.

HISTORIC DATA

During this program, geomagnetic pulsation activity was invariably recorded on days when the "A" index was 25 or more. Pulsation activity that produced the highest response on the MAD trace also occurred on these days. Various reports published by the Space Environment Service Center and its predecessor, the Telecommunication Disturbance Forecast Center, of the National Oceanic and Atmospheric Administration provided information on magnetic disturbances that reached an "A" index of 25 or more. Figures 6 and 7 have been extracted from these reports.

Figure 6 shows the number of storms with an "A" index of 25 or more, storm hours per year, and the percentage of total hours per year represented by storms during 1961-71. Figure 7 shows the monthly distribution of storm hours during the same period. The larger number on each monthly line shows the maximum number of storm hours recorded during that month over the observation period. The smaller number indicates the average number of storm hours for that month.

A study by Chapman and Bartels (1951) of magnetic data for a 58-year period indicated that the months nearest the equinoxes (March, April, September, and October) have the most storm activity. The data shown in figure 7 for a shorter period of time indicate the highest average level of activity in September. No particular peaks are associated with the other three months.

6

Figure 6 does not include all hours during which pulsation activity can interfere with MAD operations. However, it does represent all hours during which MAD operations are expected to be most severely affected.

THE ASQ-81 MAD SYSTEM

This report has dealt thus far with the effect of geomagnetic pulsation activity on the ASQ-10A MAD system. However, the newer fleet ASW aircraft use the ASQ-81 MAD system which is capable of detecting a much smaller submarine signal. The allowable in-flight noise level of this system is 0.05 gamma. A distinctive feature of this new system is a variable bandpass. Of particular importance with reference to pulsation activity are the settings on the lower end of the bandpass.

Figure 8 shows how the lower end of the bandpass varies for filter-setting options on the ASQ-81. The ASQ-10A filter bandpass curve is also shown for comparison. The curves, derived from tests with magnetometers used by NAVOCEANO, are believed to be typical of the ASQ-81 and ASQ-10A systems.

The standard bandpass setting for the ASQ-81 is 0.06 to 0.6 Hz; this curve is shown in figure 8 along with the 0.04, 0.08, and 0.1 filter settings. The upper end of the ASQ-81 bandpass can also be varied; but for this discussion, only the lower bandpass settings are important. As shown in the figure, the standard ASQ-81 bandpass is slightly wider at the lower end of the curve than the ASQ-10A bandpass. This means that pulsation amplitudes observed on an ASQ-81 trace will be somewhat higher at the standard setting than those observed with an ASQ-10A.

Amplitude of pulsation activity on the ASQ-81 trace depends on the setting of the lower bandpass switch. Table 3 compares the effect of lower bandpass settings on the amplitude of pulsation activity. The table shows the percentage of the amplitude of a pulsation of a given period or frequency that will pass through the filter and appear as noise on the recorded trace. The lower line of the table allows comparison of the ASQ-81 with the ASQ-10A.

Table 3 shows that the lower bandpass setting makes a considerable difference in the possible observed amplitude of pulsation-caused noise. During magnetically disturbed periods, the 0.1 filter setting would be more desirable than the standard 0.06 setting. The table shows that pulsations with periods of 10 seconds would be reduced 19 percent more with a 0.1 setting instead of a 0.06 setting, 20-second pulsations would be reduced 35 percent more, and 30-second pulsations would be eliminated. This reduction in background noise would improve the signal to noise ratio and make target identification easier.

CONCLUSIONS AND RECOMMENDATIONS

In connection with MAD systems, the term "geomagnetic noise" is commonly applied to interference caused by magnetic storms and micro-pulsations. This form of noise has been so severe on some occasions that the MAD operator thought the system was malfunctioning. Even if the

7

TABLE 3.   COMPARISON OF PULSATION AMPLITUDES FOR
VARIOUS ASQ-81 BANDPASS SETTINGS

PULSATION PERIODS OR FREQUENCIES	10s 0.1 Hz	20s 0.05Hz	30s 0.03 Hz
	PERCENT OF PULSATION THROUGH FILTER		
ASQ-81 SETTINGS			
0.04 Hz	95	68	42
0.06 Hz	89	56	28
0.08 Hz	77	36	11
0.1 Hz	70	21	--
ASQ-10A FIXED			
at 0.07 Hz	81	48	24

operator were able to recognize geomagnetic noise for what it was, the
fixed-filter MAD systems of the past did not permit adjustment to mitigate
this problem. The variable bandpass option of the ASQ-81 system enables
the operator to lessen the impact of micropulsation activity. The MAD
operator needs timely information on the state of the magnetic field, so
that he can set the bandpass properly.

Present information on the state of the magnetic field consists
mainly of the WWV geoalerts broadcast each hour. The geoalerts describe
the condition of the magnetic field using very general descriptors such
as quiet, unsettled, minor magnetic storm, and major magnetic storm.

General descriptors are of some use to MAD operators; however, a
better information system could be made available. A geoalert system
designed specifically to assist MAD operations would utilize geomagnetic
field monitoring systems at certain key locations. A suggested network
would consist of stations on the U.S. east coast, Iceland, U.K., Azores,
U.S. west coast, Hawaii, Alaska, Japan, and Guam. These locations would
provide coverage for most of the important ASW operating areas in the
North Atlantic and North Pacific. Monitoring stations located in remote
areas of existing patrol squadron bases could consist of an optical pumping
magnetometer with an ASQ-81 filter network. A data display consisting of
a 2-channel recorder to show filtered and unfiltered traces could be
placed at the weather briefing station. Thus, personnel concerned with
MAD operations could be informed of current geomagnetic conditions. When
a magnetic disturbance might affect MAD operations, crews could be advised
of the best filter setting to use. Information collected at any monitoring
station would be available to other patrol squadron bases and to carrier

8

ASW aircraft in the vicinity. Real-time identification cf geomagnetic noise could also reduce MAD maintenance time by helping to identify certain unusual types of noise. Data collected by monitoring stations would also be valuable for application to radio communication and electronic navigation problems.

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Miles, D. P., and R. P. Lepping, Geomagnetic Fluctuation Studies at the U.S. Naval Air Development Center, Report No. NADC-AW 6240, 1962.
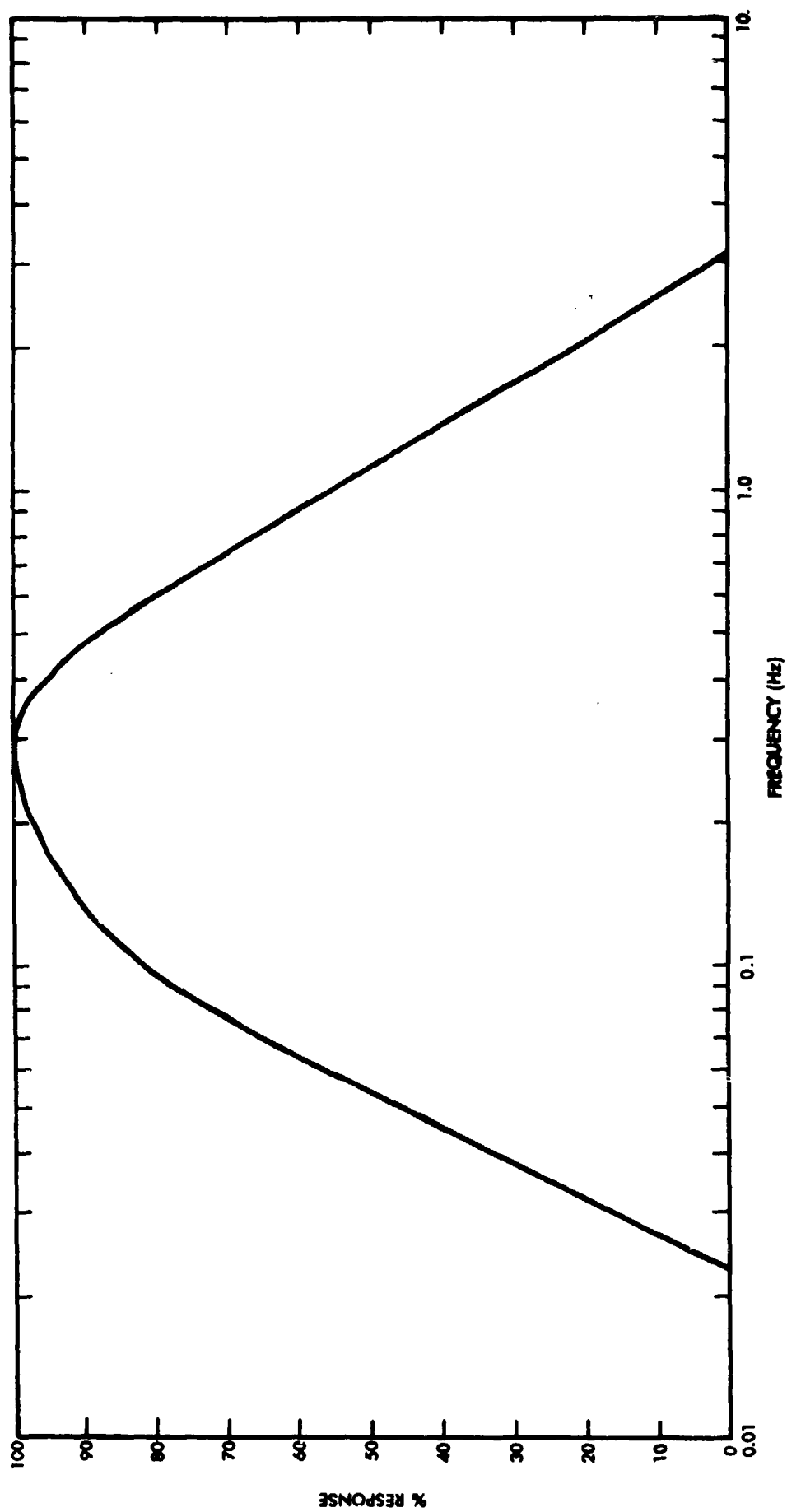
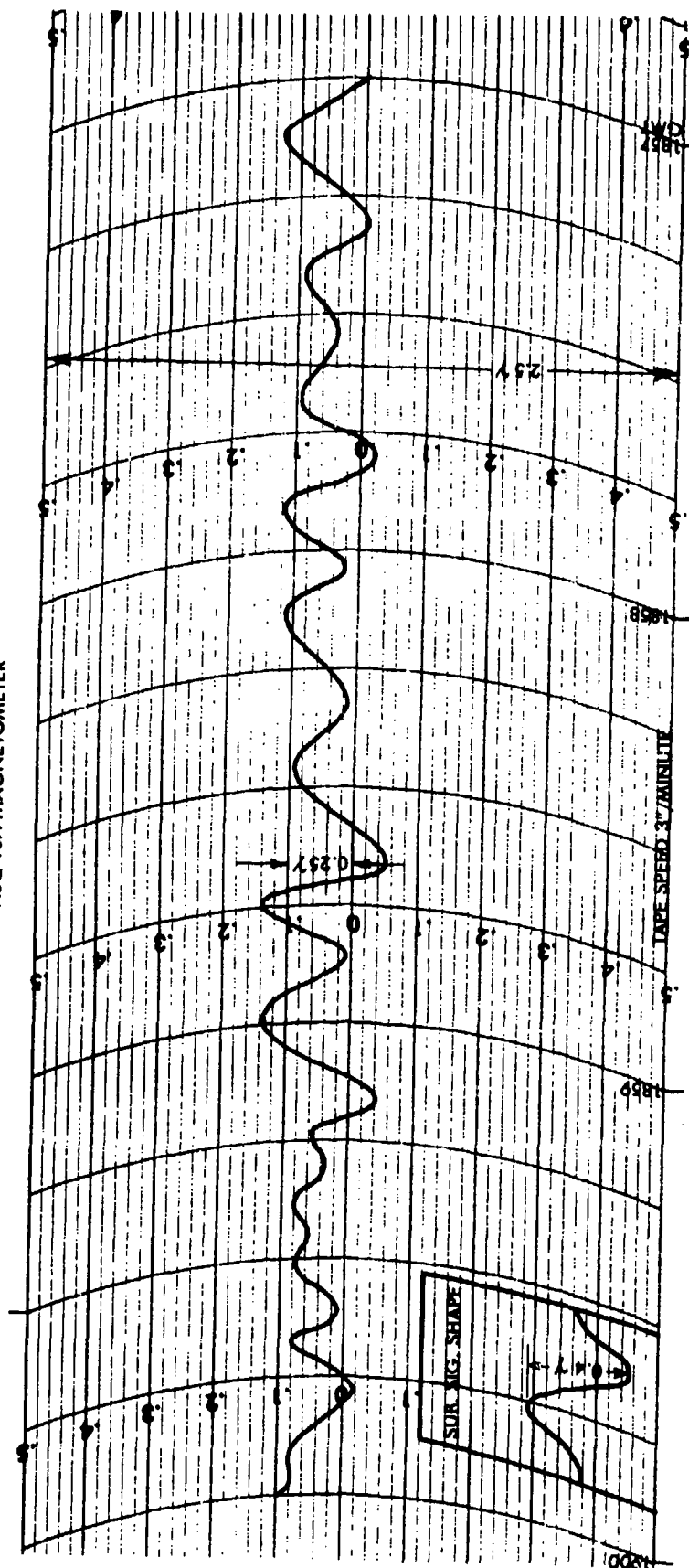FIGURE 1. AMPLITUDE RESPONSE CURVE FOR THE FILTER USED IN AN AN/ASQ-10A MAD SYSTEM
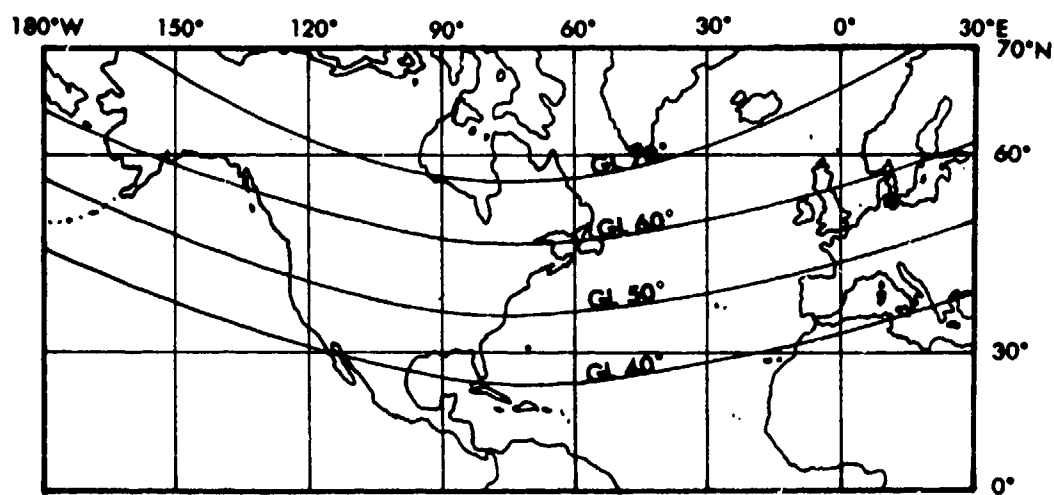
(After Matsushita and Campbell, 1967)

**FIGURE 2. RELATIONSHIP OF GEOGRAPHIC AND
GEOMAGNETIC LATITUDES (GL)**
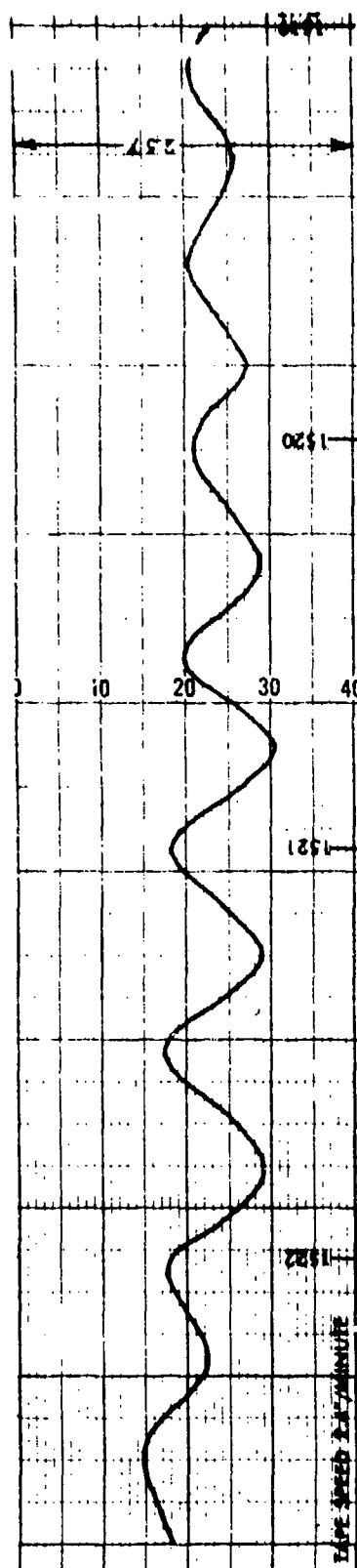
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RUBIDIUM VAPOR MAGNETOMETER
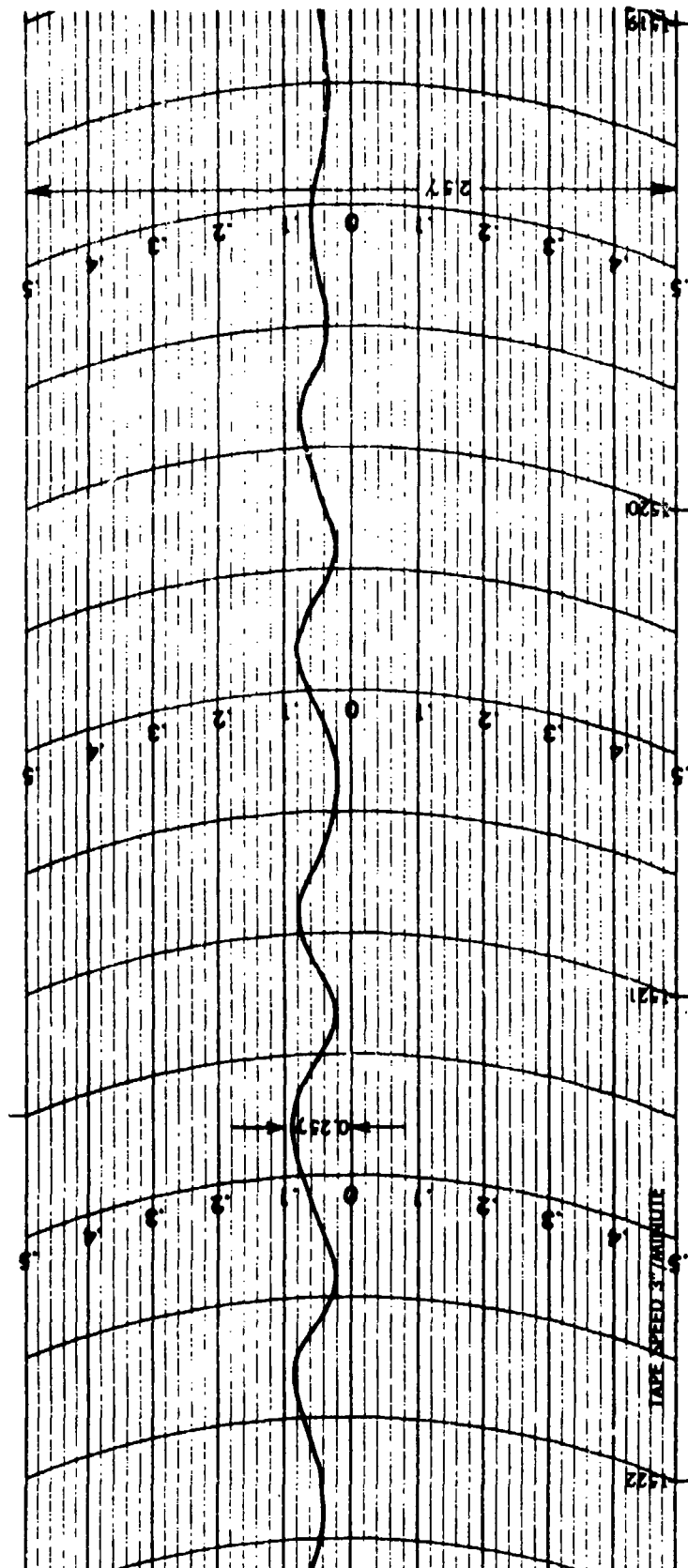
ASC-10A MAGNETOMETER

FIGURE 3. DATA SAMPLES DURING A MODERATE MAGNETIC STORM, A = 30
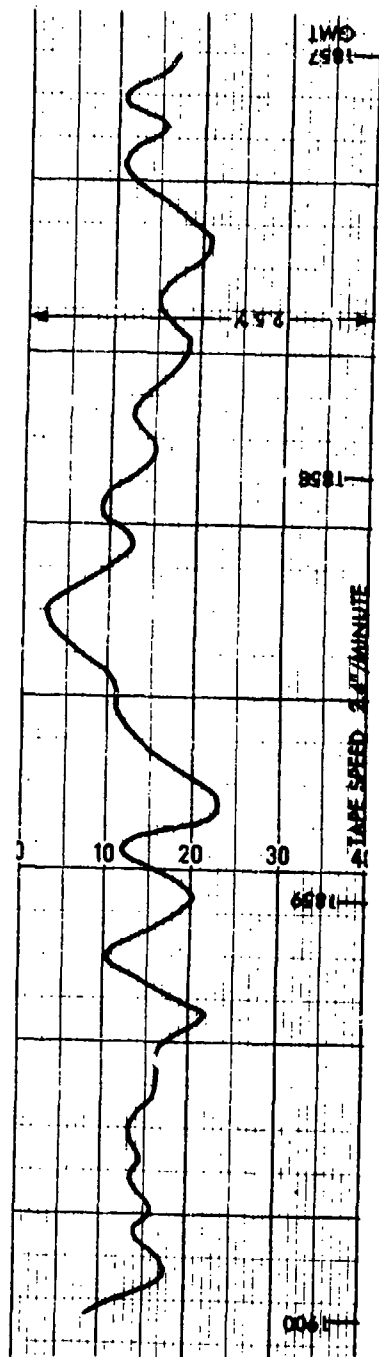
25 FEB. 1971 (A INDEX 30)

RUBIDIUM VAPOR MAGNETOMETER

ASQ-10A MAGNETOMETER

FIGURE 4. DATA SAMPLES DURING A QUIET PERIOD, A-12

31 MARCH 1972 (A IND)

13

RUBIDIUM VAPOR MAGNETOMETER

ASQ-10A MAGNETOMETER

POSSIBLE SUB.
SIGNAL ?

TAPE SPEED 3"/MINUTE
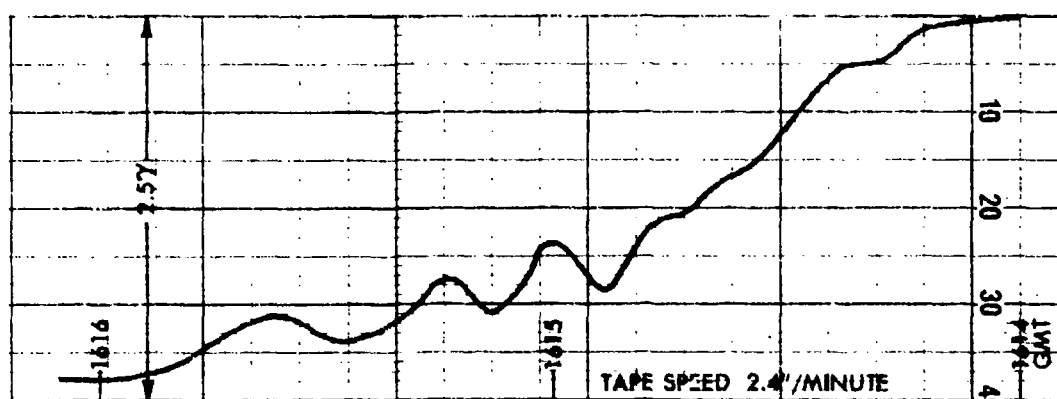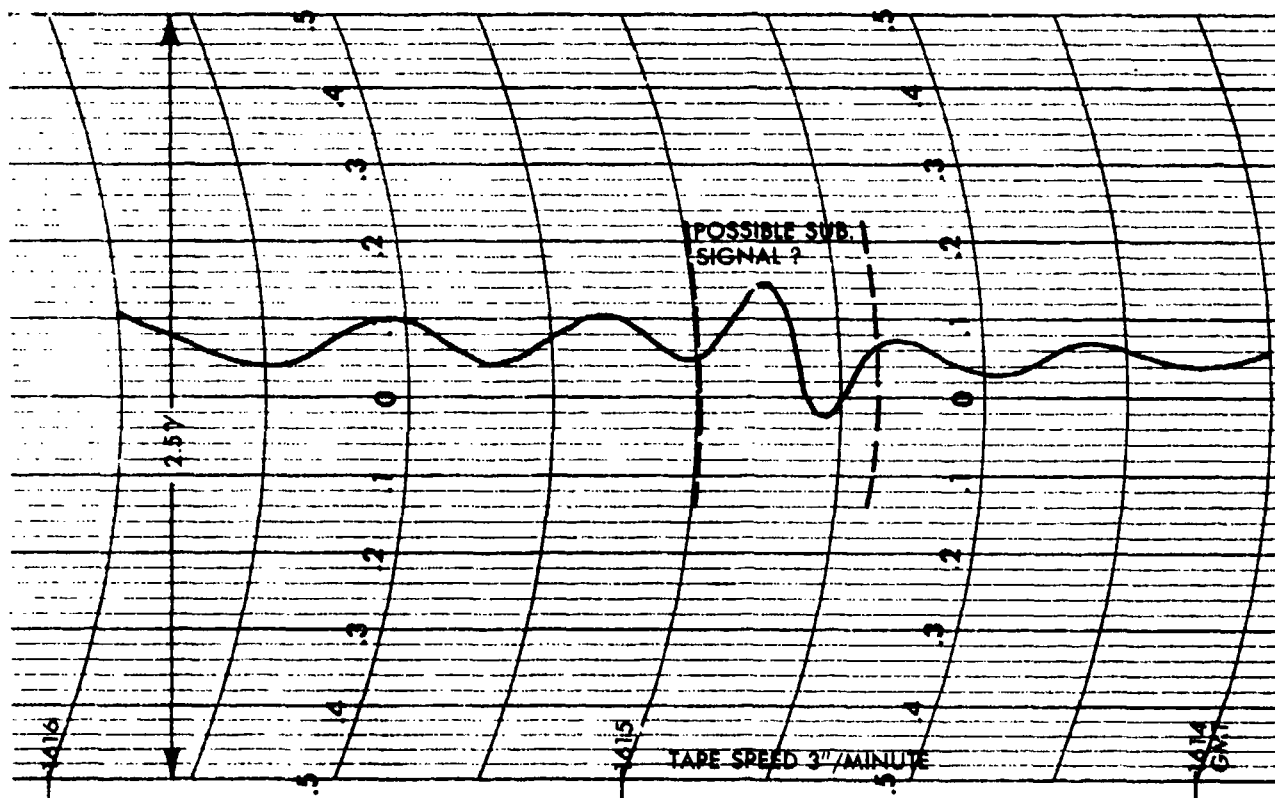
14 DEC. 1970 (A INDEX 56)

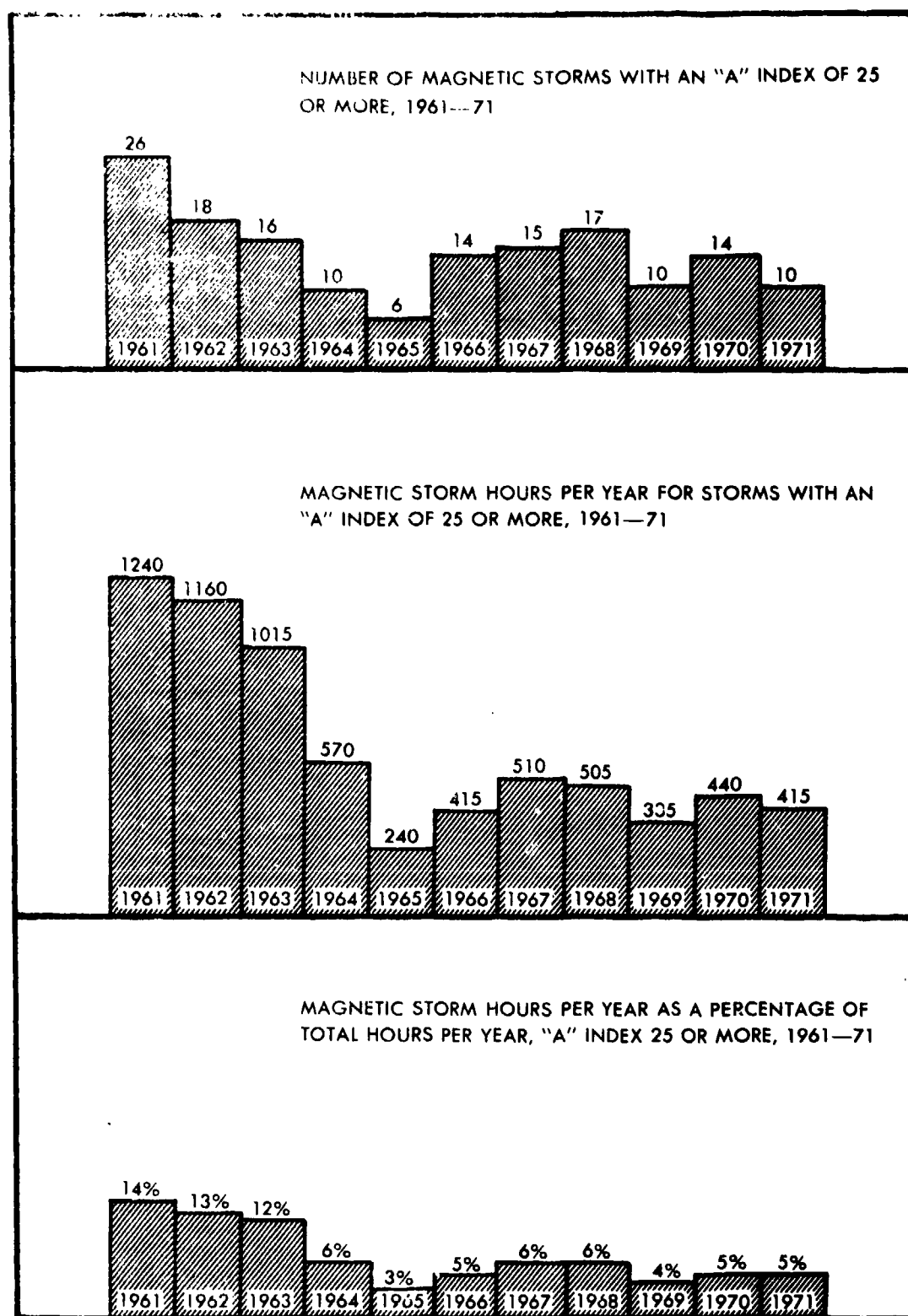FIGURE 5. DATA SAMPLES DURING A SEVERE MAGNETIC
DISTURBANCE, A = 56

14

FIGURE 6. SUMMARY OF MAGNETIC STORM HOURS WITH
AN "A" INDEX OF 25 OR MORE, 1961—71

MAXIMUM NUMBER AND AVERAGE NUMBER OF STORM HOURS PER
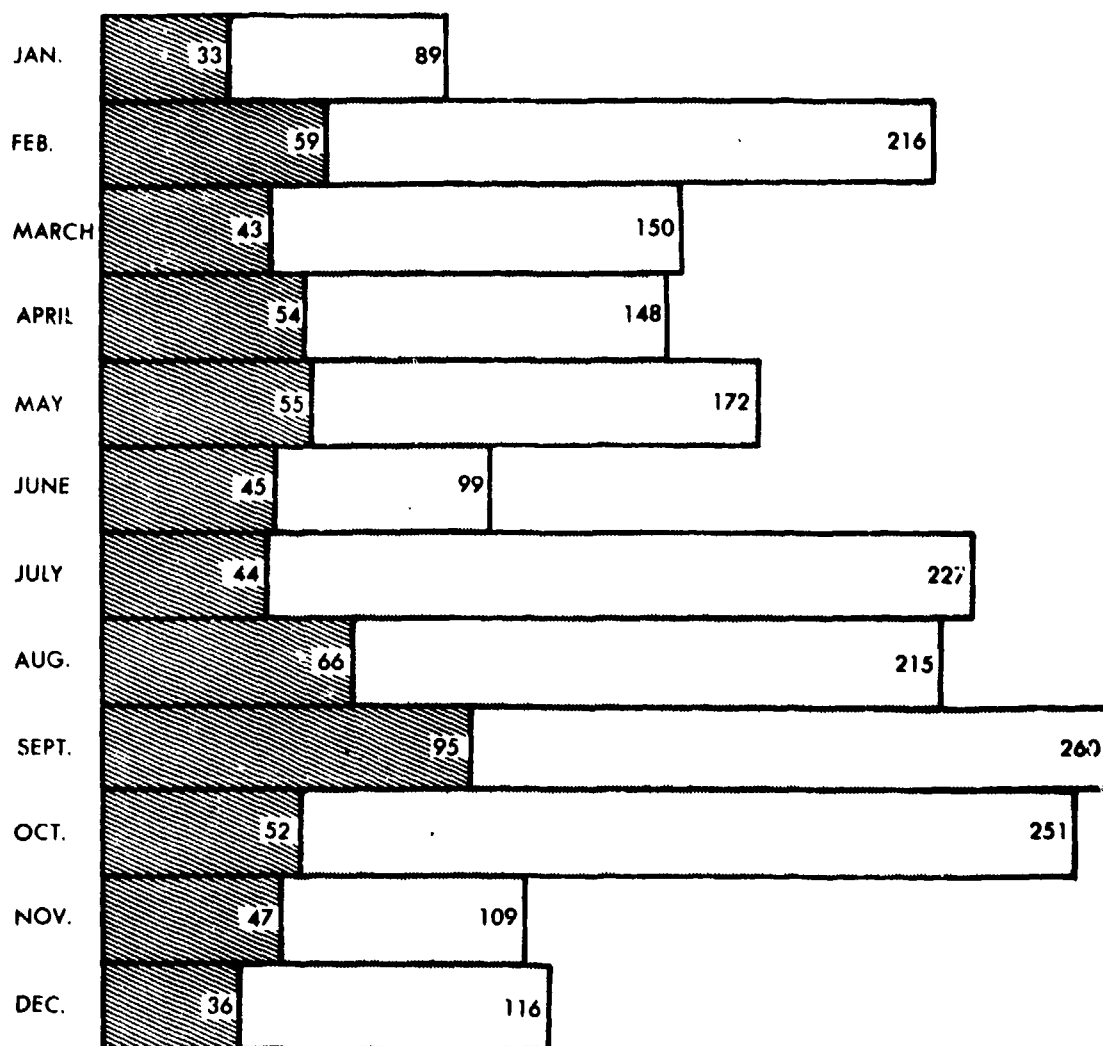MONTH, "A" INDEX OF 25 OR MORE, 1961—71

Month	Average	Maximum
JAN.	33	89
FEB.	59	216
MARCH	43	150
APRIL	54	148
MAY	55	172
JUNE	45	99
JULY	44	227
AUG.	66	215
SEPT.	95	260
OCT.	52	251
NOV.	47	109
DEC.	36	116

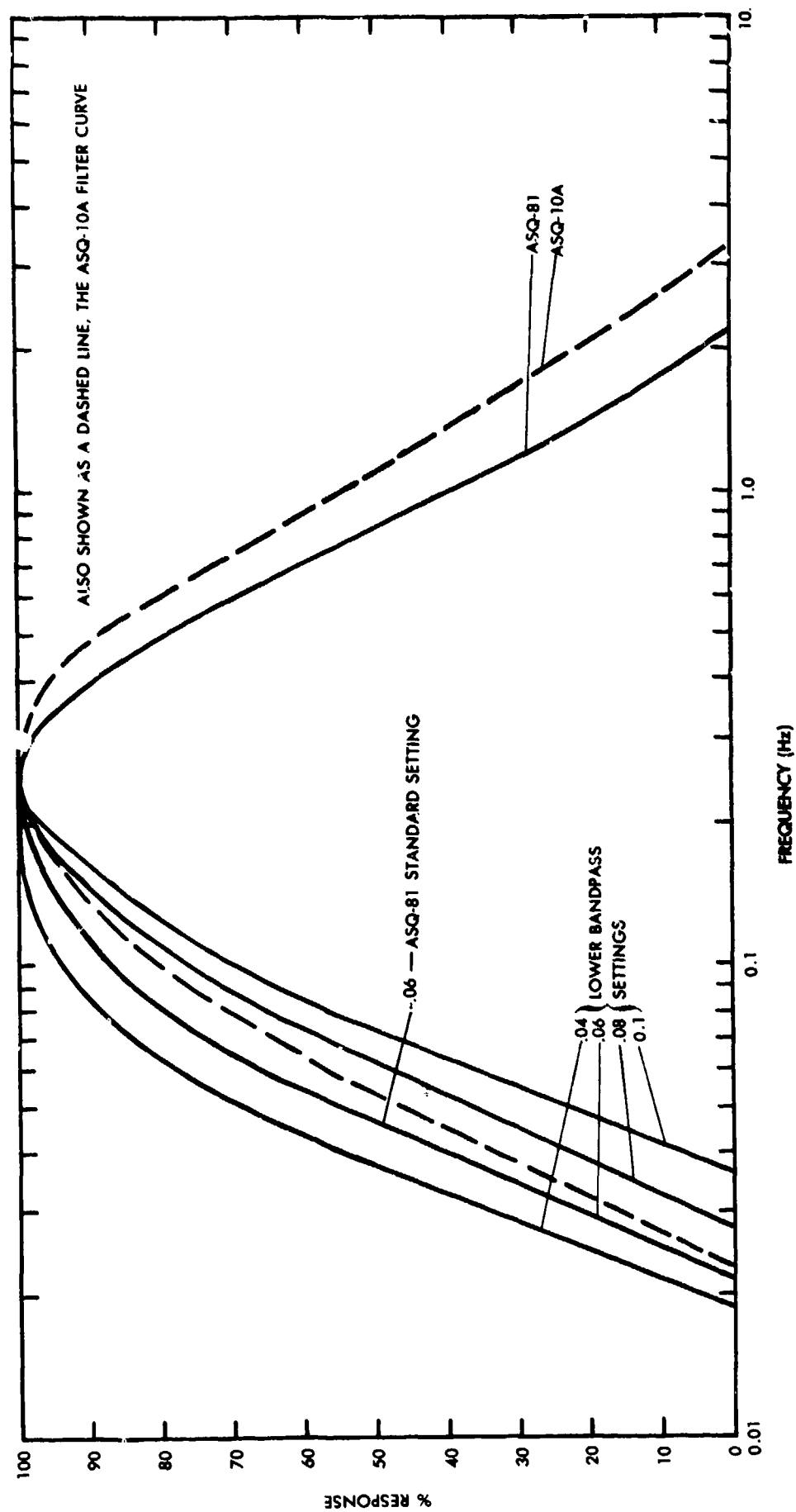FIGURE 7. SUMMARY OF STORM HOURS PER MONTH, 1961—71

16

FIGURE 8. AMPLITUDE RESPONSE CURVES FOR THE ASQ-81 MAD SYSTEM

17

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